A STUDY OF HAIRLINING

BY

JOHN EDWARD COX

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IN THE GRADUATE COLLEGE OF THE
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ACKNOWLEDGMENT

The author wishes to express his gratitude to Dr. A. I. Andrews, Head of the Department of Ceramic Engineering, for his continued advice and guidance throughout the course of this work. Gratitude is also extended to Dr. A. L. Friedberg for his many helpful suggestions, and to Professor A. W. Allen for his advice and work in the preparation of photographs and photomicrographs. Finally, the author wishes to thank The Lakefield Nepheline Syenite Corporation, of Ontario, Canada, and the Great Lakes Foundry Sand Company, of Detroit, Michigan, whose Fellowship at the University of Illinois has made this work possible.

A STUDY OF HAIRLINING

I. Introduction

Hairlining is an enamel defect which appears as a series of lines in an enamel surface. These lines are not in random directions, but exhibit some general pattern; they may radiate from some common area, they may be parallel, or they may form some family of similar curves. Hairlines form during firing as a result of cracking of a previously fired coating and the reactions which occur along the cracks. However, hairlines exist in a continuous enamel surface; they are not open cracks, and in this respect they differ from craze lines.

II. Object of Investigation

The object of this study was two-fold; first, to develop a hairlining test which would be reproducible, simple, and inexpensive, and secondly, to study the progress of hairline formation and the factors which affect it.

III. Experimental Procedure

In the development of a satisfactory hairlining test, several possible test methods were investigated with regard to reproducibility and simplicity. In general, distortion of a 4 x 8-inch test piece of 18-gauge enameling iron was effected by the presence of a smaller piece of heavy gauge enameling iron, either welded or merely placed, on the back of the test piece. Modifications of the most satisfactory test method were made to eliminate some undesirable features, and variables were investigated and standardized.

The hairlining test was used to study the mechanism of hairline formation and the factors which affect it.

IV. Results and Discussion

1. A Test for Hairlining

The specimen for the hairlining test consists of a 4 x 8-inch

piece of 18-gauge enameling iron in which a condition of strain during firing is produced by the presence of an unattached 2 x 2-inch piece of 16-gauge enameling iron placed on the top center. Both the test piece and the straining piece are acid pickled and then separated curved in a wooden mold of 1½ feet radius of curvature. The permanent deformation in the 8-inch piece is approximately ⅛ inch. This amount of curvature controls the direction of distortion which occurs during subsequent firings. After being curved, the specimen is ground-coated by dipping, with its convex surface upward, to give a fired thickness of 9 mils. The straining piece is also dipped, but is wiped clean on its convex surface so that only one thickness of enamel exists between the two pieces of iron during firing. The 8-inch test specimen is supported across a 5½-inch span during firing, with its convex surface downward, and with the 2 x 2-inch straining piece resting on the top center, also with its convex surface downward so as to closely fit the test specimen. After the ground-coat fire, the test surface (convex surface of the 4 x 8-inch piece) is examined for uniformity of thickness, or for specific characteristics of a variable being studied. Ground-coated specimens are then re-fired for 20 seconds, at the cover-coat firing temperature, and examined for the amount and severity of hairlines after by spraying, to an application weight of 20 gms./sq. ft., dry, and examined for cracks. Other specimens are cover-coated the cover-coat fire.

Examination of the crack patterns produced during the 20 seconds re-fire gives a first indication of the hairlining tendency in that long, continuous cracks result in more severe hairlining than do shorter discontinuous cracks. The final evaluation of the hairlining tendency depends on the general over-all appearance of the specimen after the cover-coat fire, as compared on the basis of amount of hairlines and the severity of the lines. Used in this manner, the test indicates relative hairlining tendency as affected by ground-coat and cover-coat properties, and by firing procedure.

2. Progress of Hairline Formation

The first stage in the formation of hairlines during the cover-coat fire is the cracking of the ground coat. This may occur within 15 seconds, and is immediately followed by cracking of the cover-coat bisque. The cover-coats cracks widen as fusion begins and as the cover-coat layer starts to bond to the ground coat. When the ground coat softens, it is slightly raised into the cover-coat cracks, due to the surface tension forces of the enamels at the break. As heating is continued, both the cover coat and the ground coat become fluid and start to heal the breaks in the cover-coat surface. The relative extent to which the ground coat or the cover coat fills the cracks is determined by the surface tension and fluidity of the two layers. Finally, the cover-coat surface becomes smooth and continuous with no further improvement on continued firing. For the test specimen used in this study, the hairline formation was completed in 1¼ minutes of the cover-coat fire.

3. The Influence of Enameling Variables on Hairlining

Ground coat properties first affect hairlining at the time of the ground-coat cracking. At this stage, the degree of homogeneity of the fired ground coat is important and the hairlining tendency increases as the degree of homogeneity is increased. At this stage, refractory mill additions of nepheline syenite or silica aid in reducing hairlining by breaking up the cracks into short discontinuous cracks rather than permitting the formation of long cracks. A dense bubble structure in the fired ground coat has the same effect. In the second stage of the hairline formation, after the enamel softens, the hairlining tendency varies directly with the ground-coat fluidity. The ground coats which soften sooner and become more fluid, are more readily and completely drawn-up into the cracks in the bisque cover coat, and result in more severe hairlining.

The most significant cover-coat variables are thickness and fluidity, and an increase in either of these factors increases

the hairline resistance. Variations in mill additions to the cover coat, and variations in the methods of application and drying, also affect hairlining but are limited by good enameling practice.

4. Considerations of Stress Development in Test Specimen

Using the test specimen previously mentioned, and varying the firing schedule, it was found that two critical temperatures exist in the re-firing of ground-coated test pieces. The lower critical temperature is that furnace temperature to which the specimen may be directly subjected without cracking, and the upper critical temperature is that specimen temperature at which the specimen may be directly transferred to a high temperature zone at the enamel maturing temperature without cracking. For the test specimen used in this study, these temperatures were found to be about 750°F. and 900°F. respectively. Cracking does not occur below the lower critical temperature because the stresses due to distortion caused by uneven heating are less than the tensile strength of the enamel. Above the upper critical temperature, cracking does not occur because the enamel softens and yields before the stress becomes sufficient to cause cracking.

During the initial ground-coat cooling, no cracking occurred, but residual stresses existed in the cooled ground coat due to uneven rates of cooling. In some cases, the residual stresses resulted in ground-coat cracking during re-fire even though the rate of heating was slow and uniform. The severity of the cooling stresses varies with the ground-coat expansion characteristics, thickness, and refractory mill additions, but could be sufficiently reduced to allow successful re-firing by slow cooling through the temperature range of 1050 to 800°F. after the initial ground-coat fire. After this cooling procedure, hairline-free specimens could be obtained during the cover-coat fire, by first heating only to the lower critical temperature until the specimen was at a uniform temperature, then slowly increasing the temperature to the upper critical temperature, and then transferring the specimen to the

cover-coat maturing temperature of 1500°F.

V. Summary

A test for hairlining was developed which is simple to perform and which gives reproducible results. By means of this test, the progress of hairline formation and the factors which affect it were examined. It was found that hairlining is caused by cracking of the ground-coat glass during subsequent firing and the reactions which occur between the ground coat and cover coat along the cracks. Cracking of the ground coat is due chiefly to the distortion caused by uneven heating during the cover-coat fire, but residual stresses due to previous cooling can be partly responsible for the cracking. Refractory mill additions to the ground coat, increased refractoriness of ground-coat frits, increased fluidity of cover-coat frits, and increased thickness of cover coat, aid in reducing the hairlining tendency. For the test specimen used in this study, it is possible to prevent hairlining by improving the firing schedule.

VITA

John Edward Cox was born on March 28, 1923, in Danville, Illinois, and later moved to Bloomington, Illinois. After graduating from Trinity High School in Bloomington, Illinois, in 1941, he attended Illinois State Normal University for one semester. In 1943 he entered the Army of the United States and served in the American and India-Burma Theaters. Upon discharge from the Army in February, 1946, he again entered Illinois State Normal University and remained there until August, 1947. In September, 1947, he transferred to the University of Illinois and received the degree of Bachelor of Science, with honors, from that institution in February, 1950. He began his graduate work there at that time and held a Graduate Fellowship until June, 1953, receiving the degree of Master of Science in February, 1951.

He is a member of the American Ceramic Society, Sigma Xi, and Keramos.

Publication: J. E. Cox and R. L. Cook, "The Use of Nepheline Syenite in Porcelain Enamels", Finish, 9 (2) 30-1 (1952).